4. Forces, Density and Pressure

4.2 Equilibrium of forces

Paper 2

Question Paper

1 A pinball machine uses a spring to launch a small metal ball of mass 4.5×10^{-2} kg up a ramp. The spring is compressed by 8.0×10^{-2} m and held in equilibrium, as shown in Fig. 4.1.

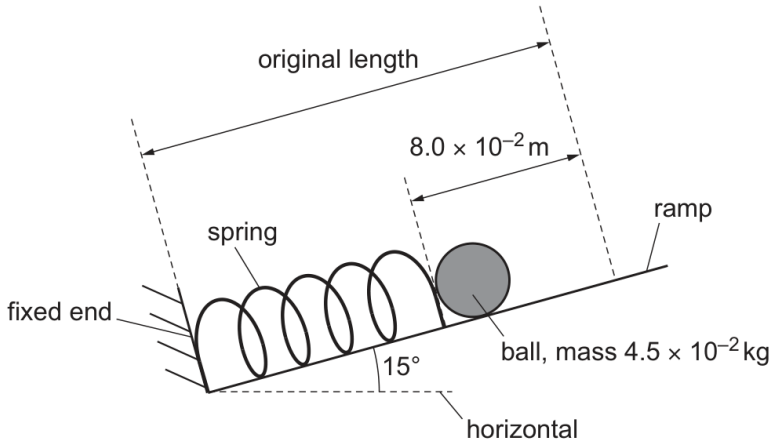


Fig. 4.1 (not to scale)

The ramp is at an angle of 15° to the horizontal.

(c) The ball comes to rest on a horizontal trapdoor of negligible mass at a distance *d* from its pivot.
A force *F* acts vertically downwards at a distance of 2.0 cm from the pivot, as shown in Fig. 4.2.

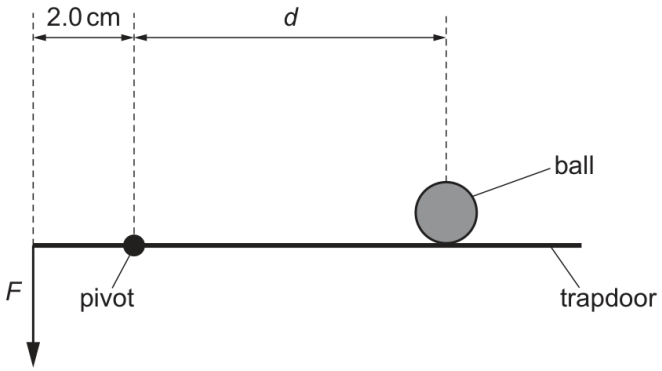


Fig. 4.2 (not to scale)

(i) The trapdoor is in equilibrium when *F* is 1.7 N.

Calculate *d*.

d = ... m [2]

(ii) Force *F* is decreased from 1.7 N.

State the direction of the resultant moment about the pivot on the trapdoor.

..... [1]

2 **(b)** A sphere falls vertically through a liquid that has density 830 kg m^{-3}. The sphere has radius r and constant velocity v, as shown in Fig. 1.1.

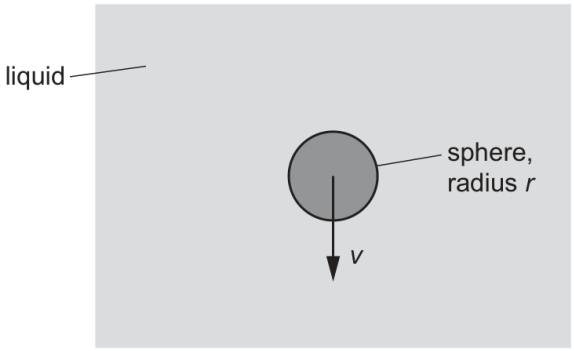


Fig. 1.1

(ii) State an equation showing the relationship between the magnitudes of the weight W, drag force D and upthrust U acting on the sphere.

..... [1]

3 **(b)** State the conditions necessary for an object to be in equilibrium.

.....

.....

..... [2]

(c) A wire is used to hold a uniform shelf AB horizontally in equilibrium as shown in Fig. 3.2.

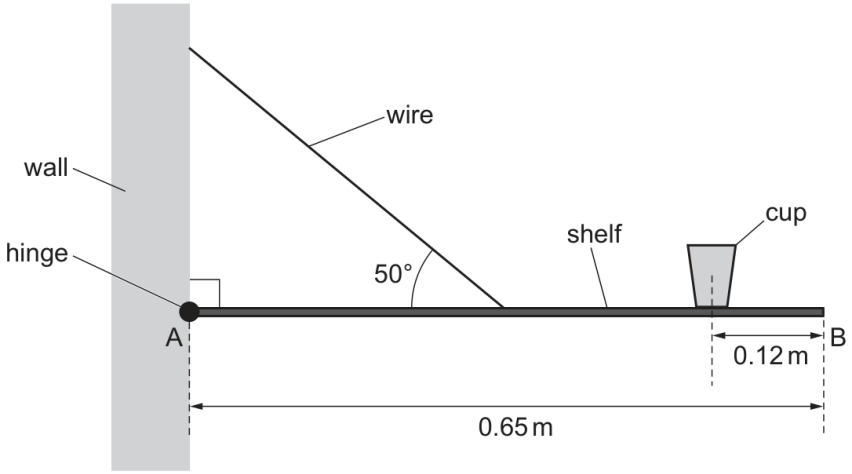


Fig. 3.2 (not to scale)

The wire is connected to the midpoint of shelf AB at an angle of 50° to the horizontal. The shelf is attached to a wall by a hinge at A. The length of shelf AB is 0.65 m and its weight is 33 N.
A cup of weight 1.5 N rests on the shelf with its centre of gravity at a horizontal distance of 0.12 m from B.

(i) By taking moments about A, determine the tension in the wire.

tension = ... N [3]

4 A rigid uniform beam of weight *W* is connected to a fixed support by a hinge, as shown in Fig. 2.1.

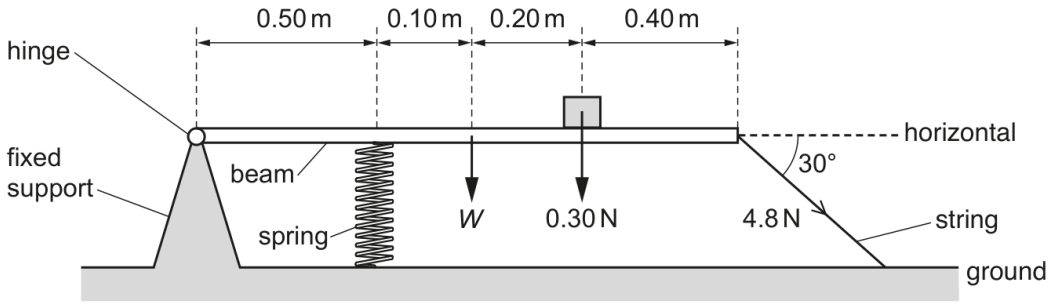


Fig. 2.1 (not to scale)

A compressed spring exerts a total force of 8.2 N vertically upwards on the horizontal beam. A block of weight 0.30 N rests on the beam. The right-hand end of the beam is connected to the ground by a string at an angle of 30° to the horizontal. The tension in the string is 4.8 N. The distances along the beam are shown in Fig. 2.1.

The beam is in equilibrium. Assume that the hinge is frictionless.

(a) (ii) By taking moments about the hinge, determine the weight *W* of the beam.

W = ... N [3]

(iii) Calculate the horizontal component of the force exerted on the beam by the hinge.

force = ... N [1]

5 **(b)** Two blocks are on a horizontal beam that is pivoted at its centre of gravity, as shown in Fig. 2.1.

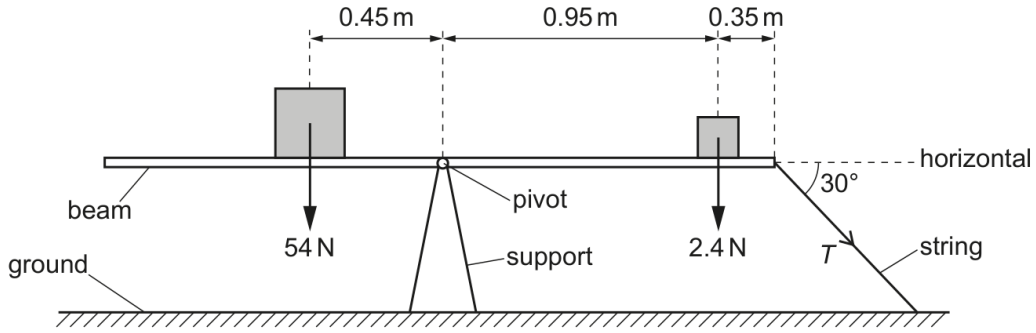


Fig. 2.1 (not to scale)

A large block of weight 54 N is a distance of 0.45 m from the pivot. A small block of weight 2.4 N is a distance of 0.95 m from the pivot and a distance of 0.35 m from the right-hand end of the beam.

The right-hand end of the beam is connected to the ground by a string that is at an angle of 30° to the horizontal. The beam is in equilibrium.

(i) By taking moments about the pivot, calculate the tension T in the string.

T = ... N [3]

(ii) The string is cut so that the beam is no longer in equilibrium.

Calculate the magnitude of the resultant moment about the pivot acting on the beam immediately after the string is cut.

resultant moment = ... N m [1]

6 A hot-air balloon floats just above the ground. The balloon is stationary and is held in place by a vertical rope, as shown in Fig. 2.1.

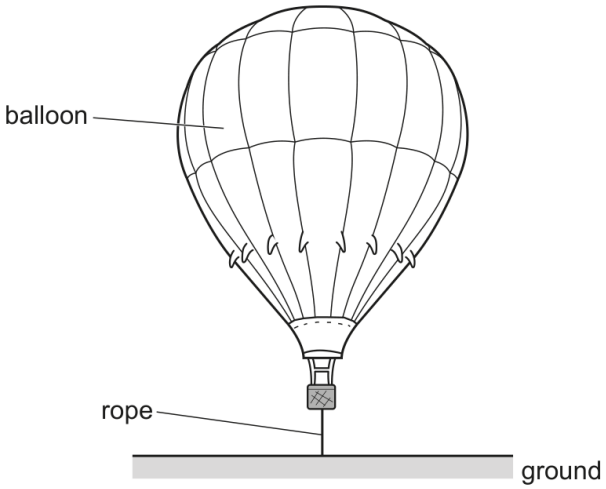


Fig. 2.1

The balloon has a weight W of 3.39×10^4 N. The tension T in the rope is 4.00×10^2 N.
Upthrust U acts on the balloon.
The density of the surrounding air is $1.23\,\text{kg}\,\text{m}^{-3}$.

(a) (i) On Fig. 2.1, draw labelled arrows to show the directions of the three forces acting on the balloon. [2]

7 **(b)** A non-uniform rod XY is pivoted at point P, as shown in Fig. 2.1.

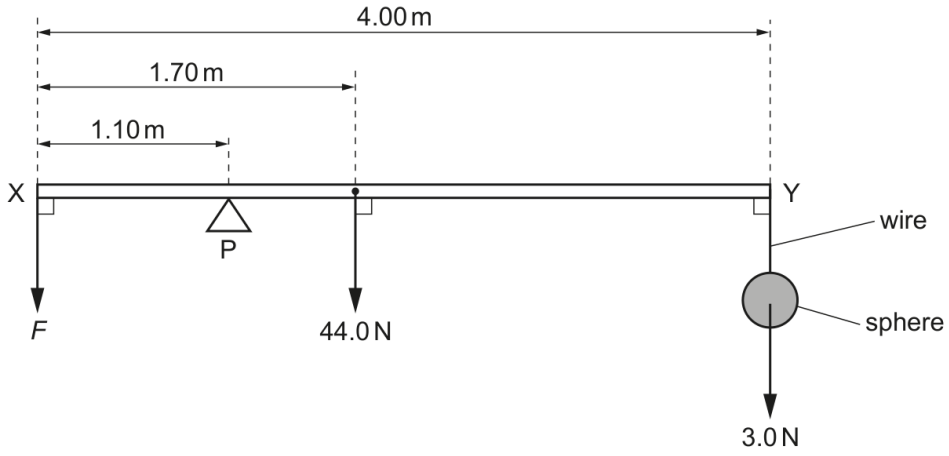


Fig. 2.1 (not to scale)

The rod has length 4.00 m and weight 44.0 N. The centre of gravity of the rod is 1.70 m from end X of the rod. Point P is 1.10 m from end X.

A sphere hangs by a wire from end Y of the rod. The weight of the sphere is 3.0 N. The weight of the wire is negligible.

A force *F* is applied vertically downwards at end X so that the horizontal rod is in equilibrium.

(i) By taking moments about P, calculate *F*.

F = ... N [3]

(ii) Calculate the force exerted on the rod by the pivot.

force = ... N [1]

(c) The sphere in **(b)** is now immersed in a liquid in a container, as shown in Fig. 2.2.



Fig. 2.2

The density of the liquid is 1100 kg m^{-3}. The upthrust acting on the sphere due to the liquid is 2.5 N. The magnitude of F is unchanged so that the horizontal rod is **not** in equilibrium.

(ii) Calculate the magnitude and direction of the resultant moment of the forces on the rod about P.

magnitude of resultant moment = ... N m

direction of resultant moment .....

[2]

8 **(b)** A block is pulled up a slope by a wire attached to a motor, as shown in Fig. 3.1.

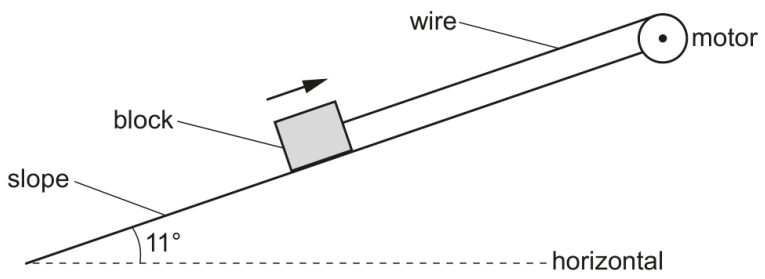


Fig. 3.1 (not to scale)

The useful power output of the motor is 56 W. The block has a weight of 430 N and travels with constant velocity along the slope at an angle of 11° to the horizontal.

Assume that there are no resistive forces opposing the motion of the block.

(i) Calculate the tension T in the wire.

T = ... N [2]

9 A sphere is attached by a metal wire to the horizontal surface at the bottom of a river, as shown in Fig. 2.1.

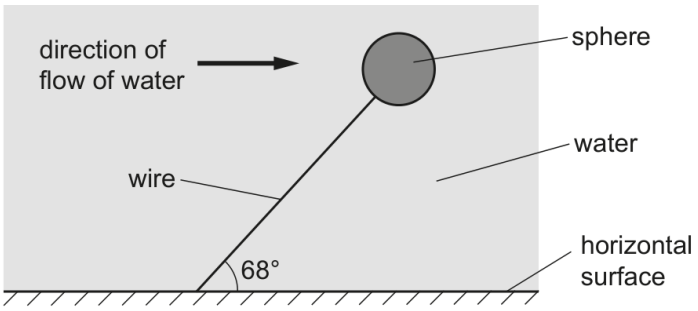


Fig. 2.1 (not to scale)

The sphere is fully submerged and in equilibrium, with the wire at an angle of 68° to the horizontal surface. The weight of the sphere is 32 N. The upthrust acting on the sphere is 280 N. The density of the water is 1.0×10^3 kg m^{-3}.

Assume that the force on the sphere due to the water flow is in a horizontal direction.

(a) By considering the components of force in the vertical direction, determine the tension in the wire.

tension = ... N [2]

10 (b) A uniform beam AB is attached by a frictionless hinge to a vertical wall at end A. The beam is held so that it is horizontal by a metal wire CD, as shown in Fig. 3.1.

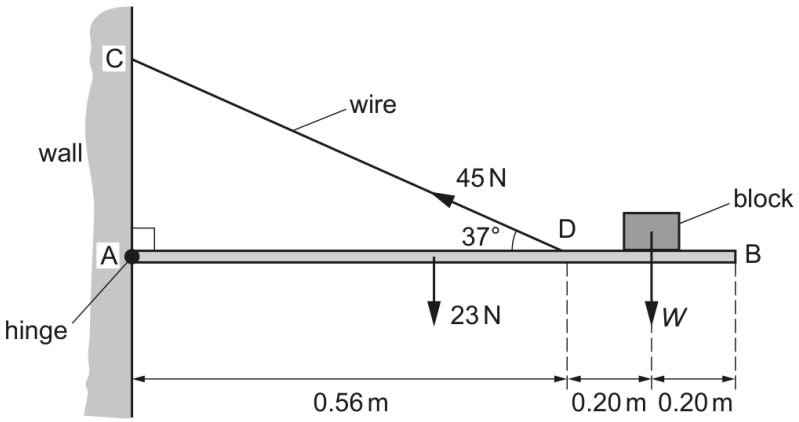


Fig. 3.1 (not to scale)

The beam is of length 0.96 m and weight 23 N. A block of weight *W* rests on the beam at a distance of 0.20 m from end B. The wire is attached to the beam at point D which is a distance of 0.40 m from end B. The wire exerts a force on the beam of 45 N at an angle of 37° to the horizontal. The beam is in equilibrium.

(ii) By taking moments about A, calculate the weight *W* of the block.

W = ... N [3]

(iii) The hinge exerts a force on the beam at end A.

Calculate the horizontal component of this force.

horizontal component of force = ... N [1]

(iv) The block is now placed closer to point D on the beam.

State whether this change will increase, decrease or have no effect on the tension in the wire.

..... [1]

11 A pendulum consists of a solid sphere suspended by a string from a fixed point P, as shown in Fig. 3.1.

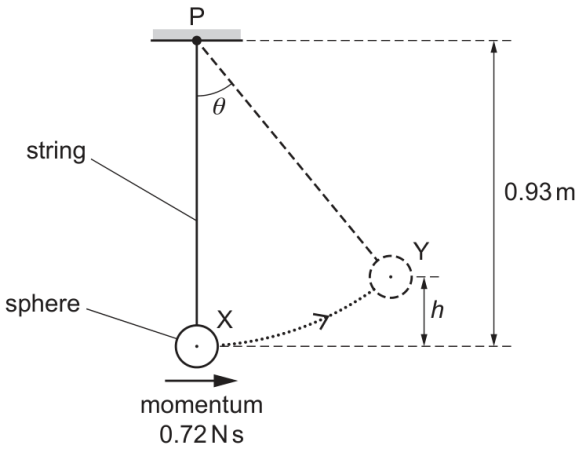


Fig. 3.1 (not to scale)

The sphere swings from side to side. At one instant the sphere is at its lowest position X, where it has kinetic energy 0.86 J and momentum 0.72 N s in a horizontal direction. A short time later the sphere is at position Y, where it is momentarily stationary at a maximum vertical height *h* above position X.

The string has a fixed length and negligible weight. Air resistance is also negligible.

(f) State and explain whether the sphere is in equilibrium when it is stationary at position Y.

.....

..... [1]

12 (b) State the conditions for an object to be in equilibrium.

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.....

.....

..... [2]

(c) A floating solid cylinder is attached by a wire to the sea bed, as shown in Fig. 1.1.

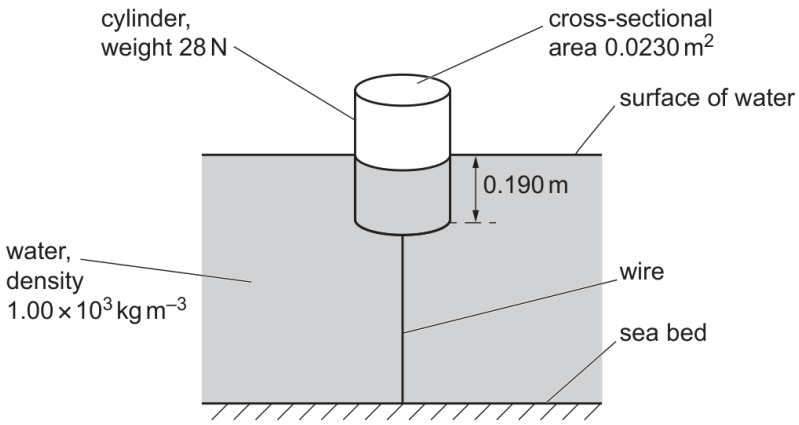


Fig. 1.1 (not to scale)

The density of the water is $1.00 \times 10^3\,\text{kg m}^{-3}$. The base of the cylinder is at a depth of 0.190 m below the surface of the water. The cylinder has a weight of 28 N and a cross-sectional area of $0.0230\,\text{m}^2$.

The wire and the central axis of the cylinder are both vertical. The cylinder is in equilibrium.

(ii) Show that the tension T in the wire is 15 N.

[1]

13 **(a)** State **two** conditions for an object to be in equilibrium.

1. .....

.....

2. .....

.....

[2]

(b) A sphere of weight 2.4N is suspended by a wire from a fixed point P. A horizontal string is used to hold the sphere in equilibrium with the wire at an angle of 53° to the horizontal, as shown in Fig. 3.1.

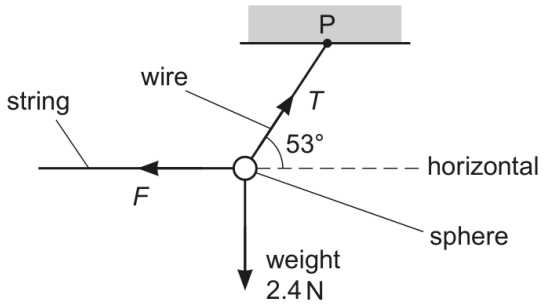


Fig. 3.1 (not to scale)

(i) Calculate:

1. the tension *T* in the wire

T = ... N

2. the force *F* exerted by the string on the sphere.

F = ... N

[2]

14 (c) A fishing rod AB, made from the rod in **(b)**, is shown in Fig. 1.2.

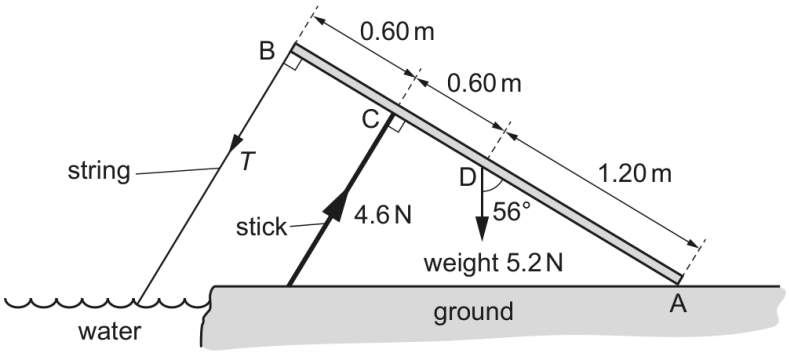


Fig. 1.2 (not to scale)

End A of the rod rests on the ground and a string is attached to the other end B. A support stick exerts a force perpendicular to the rod at point C. The weight of the rod acts at point D.

The tension *T* in the string is in a direction perpendicular to the rod. The rod is in equilibrium and inclined at an angle of 56° to the vertical.

The forces and the distances along the rod of points A, B, C and D are shown in Fig. 1.2.

(ii) By taking moments about end A of the rod, calculate the tension *T*.

T = ... N [3]

15 **(a)** A cylinder is suspended from the end of a string. The cylinder is stationary in water with the axis of the cylinder vertical, as shown in Fig. 2.1.

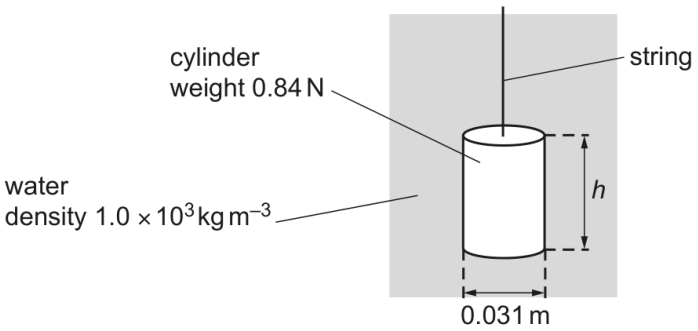


Fig. 2.1 (not to scale)

The cylinder has weight 0.84 N, height h and a circular cross-section of diameter 0.031 m. The density of the water is 1.0×10^3 kg m^{-3}. The difference between the pressures on the top and bottom faces of the cylinder is 520 Pa.

(iii) Calculate the tension T in the string.

T = ... N [1]

16 A rigid plank is used to make a ramp between two different horizontal levels of ground, as shown in Fig. 4.1.

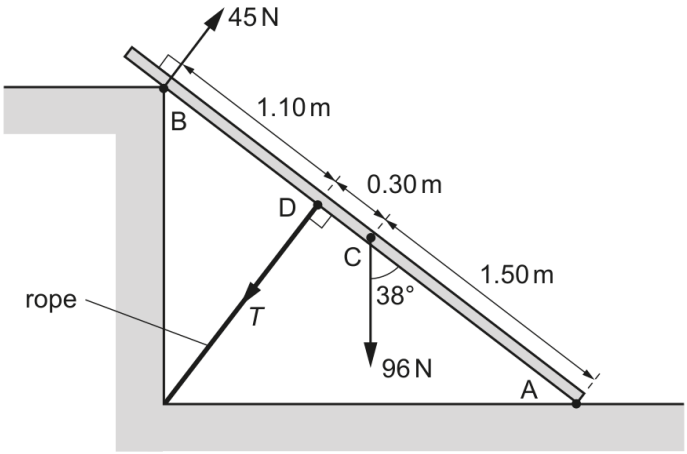


Fig. 4.1 (not to scale)

Point A at one end of the plank rests on the lower level of the ground. A force acts on, and is perpendicular to, the plank at point B. The plank is held in equilibrium by a rope that connects point D on the plank to the ground. The plank has a weight that may be considered to act from its centre of gravity C.

The rope is perpendicular to the plank and has tension *T*. The plank is at an angle of 38° to the vertical.

The forces and the distances along the plank of points A, B, C and D are shown in Fig. 4.1.

(b) By taking moments about end A of the plank, calculate the tension *T*.

T = ... N [3]

17 **(b)** The charged oil drop in **(a)** is in a vacuum between two horizontal metal plates, as illustrated in Fig. 4.1.

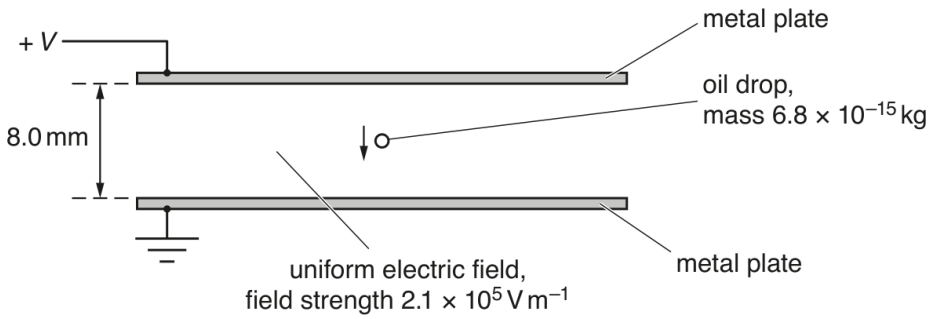


Fig. 4.1

The plates are separated by a distance of 8.0 mm. The electric field between the plates is uniform and has a field strength of $2.1 \times 10^5\,\text{V m}^{-1}$.

The oil drop moves vertically downwards with a constant speed.

(ii) Explain how the motion of the oil drop shows that it is in equilibrium.

.....

.....[1]

18 (b) A uniform square sign with sides of length 0.68 m is fixed at its corner points A and B to a wall. The sign is also supported by a wire CD, as shown in Fig. 3.1.

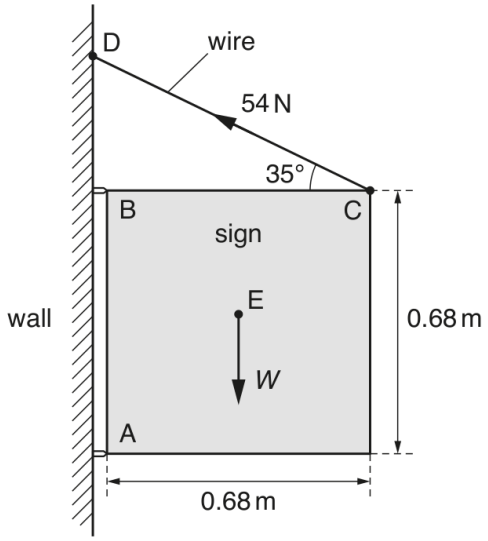


Fig. 3.1 (not to scale)

The sign has weight *W* and centre of gravity at point E. The sign is held in a vertical plane with side BC horizontal. The wire is at an angle of 35° to side BC. The tension in the wire is 54 N.

The force exerted on the sign at B is only in the vertical direction.

(iii) By taking moments about point A, show that the weight *W* of the sign is 150 N.

[2]

(iv) Calculate the total vertical force exerted by the wall on the sign at points A and B.

total vertical force = ... N [1]

19 (b) A man of weight 750 N stands a distance of 3.6 m from end D of a horizontal uniform beam AD, as shown in Fig. 4.1.

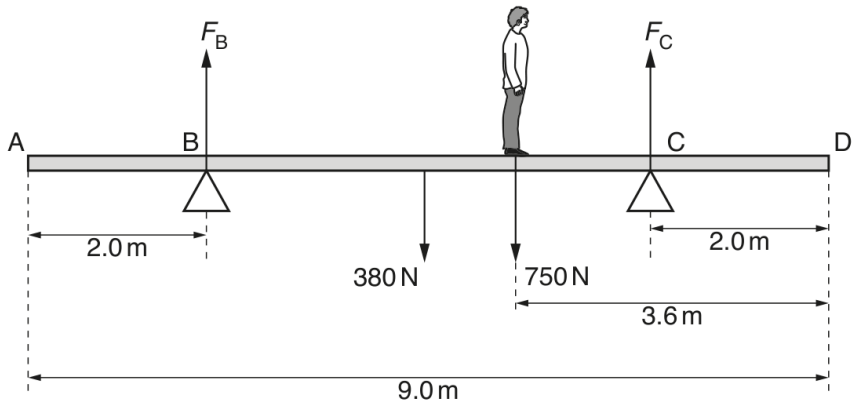


Fig. 4.1 (not to scale)

The beam has a weight of 380 N and a length of 9.0 m. The beam is supported by a vertical force F_B at pivot B and a vertical force F_C at pivot C. Pivot B is a distance of 2.0 m from end A and pivot C is a distance of 2.0 m from end D. The beam is in equilibrium.

(i) State the principle of moments.

.....

.....

..... [2]

(ii) By using moments about pivot C, calculate F_B.

F_B = ... N [2]

(iii) The man walks towards end D. The beam is about to tip when F_B becomes zero.

Determine the minimum distance x from end D that the man can stand without tipping the beam.

x = ... m [2]

20 A solid cylinder is lifted out of oil by a wire attached to a motor. Fig. 5.1 shows two different positions X and Y of the cylinder during the lifting process.

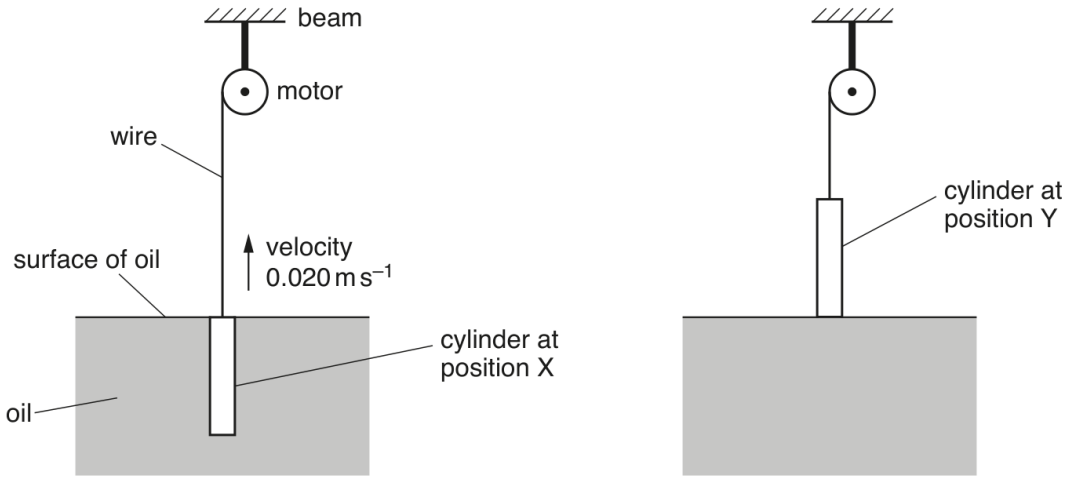


Fig. 5.1

The motor is fixed to an overhead beam.
The cylinder has cross-sectional area 0.018 m^2, length 1.2 m and weight 560 N.
The density of the oil is 940 kg m^{-3}.

Throughout the lifting process, the cylinder moves vertically upwards with a constant velocity of 0.020 m s^{-1}. The viscous force of the oil acting on the cylinder is negligible.

(c) Calculate, for the moving cylinder at position X,

(i) the tension in the wire,

tension = ... N [1]

21 **(b)** An aircraft of mass 1200 kg climbs upwards with a constant velocity of 45 m s^{-1}, as shown in Fig. 3.1.

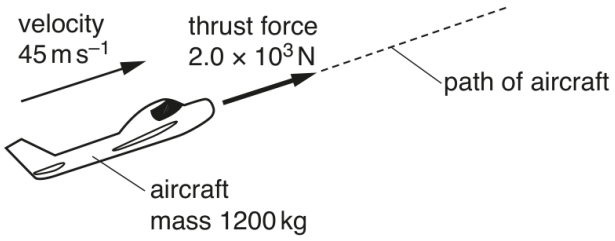


Fig. 3.1 (not to scale)

The aircraft's engine produces a thrust force of 2.0 × 10^3 N to move the aircraft through the air. The rate of increase in height of the aircraft is 3.3 m s^{-1}.

(iv) With reference to the motion of the aircraft, state and explain whether the aircraft is in equilibrium.

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..... [2]

22 **(b)** A uniform beam AB of length 6.0 m is placed on a horizontal surface and then tilted at an angle of 31° to the horizontal, as shown in Fig. 2.1.

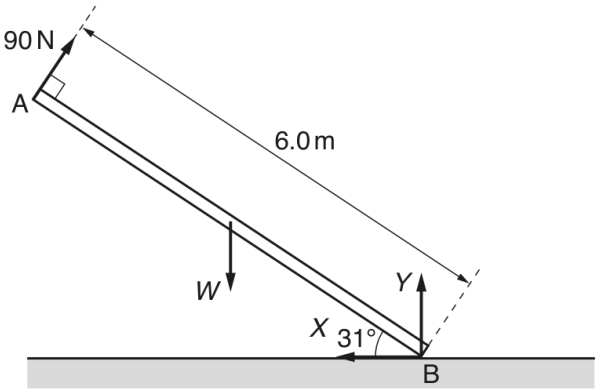


Fig. 2.1 (not to scale)

The beam is held in equilibrium by four forces that all act in the same plane. A force of 90 N acts perpendicular to the beam at end A. The weight *W* of the beam acts at its centre of gravity. A vertical force *Y* and a horizontal force *X* both act at end B of the beam.

(i) State the name of force *X*.

.....[1]

(ii) By taking moments about end B, calculate the weight *W* of the beam.

W = ... N [2]

(iii) Determine the magnitude of force *X*.

magnitude of force *X* = ... N [1]